# Collaborative Research: Generation and Transport of Vorticity and Effects on Mean Surface Currents: Wave Averages and Wave Resolving Formulations

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## LONG-TERM GOALS

Our long term goal is to understand the mechanisms controlling the intensity and spatial distribution of vortical structures, such as eddies and rip currents, evolving in the surfzone, and to understand how these flow features influence time-averaged currents, sediment transport and wave statistics.

## OBJECTIVE

Recent computations (Kirby et al, 2003a, b) have shown that computations of shear waves using either wave-averaged circulation models on the one hand, or wave-resolving Boussinesq models on the other hand, can predict very different nearshore circulation patterns when configured similarly and applied to the same field cases. This discrepancy is troubling, in that a clear basis has not been established for determining which results are typically closer to observed field conditions. In order to resolve this issue, we plan to perform comparisons of model runs for a number of time periods from the SandyDuck field experiment, and compare results to both array measurements of long-shore and cross-shore velocities as well as Doppler Sonar measurements of the study area, which provide more information on the spatial structure of flow features.

Specific objectives in support of this effort include:

1. Re-examine the energetics and spatial structure of low-frequency vortical motions as predicted by the Boussinesq model FUNWAVE and the wave-averaged circulation model SHORECIRC. The comparison will be performed using a newly-revised Boussinesq formulation which preserves an approximation for potential vorticity which is consistent with Boussinesq ordering in powers of .

2. Test model predictions against available array data and Doppler sonar data.

3. Examine the instantaneous structure of forcing for vorticity derived from Boussinesq simulations, based on the curl of momentum-preserving dissipative terms.

4. Examine the time-averaging of this forcing in the context of forcing of wave-averaged vorticity.

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5. Examine the contributions to wave-averaged radiation stress derived from Boussinesq model results, and examine the curl of this stress and its relation to the time average of instantaneous vorticity forcing.

6. Formulate the generalized Lagrangian mean (GLM) equations for Boussinesq model flows, and examine the relative importance of contributions to GLM forcing terms based on direct examination of time-resolved Boussinesq model calculations. In addition to formulating the GLM averaged equations, we will also perform Lagrangian particle trajectory calculations in the wave-resolving Boussinesq code in an attempt to verify the GLM predictions and evaluate the importance of resulting terms.

These objectives are aimed at obtaining a better understanding of the marked differences in predictions of wave-averaged circulation models and Boussinesq models for similar field conditions, as outlined below.

This report will focus on the data comparison aspect (objective 2). A separate report will focus on the modeling aspects. We also discuss preliminary work on re-examination and formulation of vertically-integrated wave-current interactions (objective 6).

## APPROACH

*Data analysis and comparison*

The first step is to develop the routines to put the data into forms suitable for model comparisons. Next, detailed analysis of the effective averaging in time and space are determined, to determine what level of detail and what statistical measures are appropriate for comparison. Finally, we identify general conceptual "tests" that are best suited to both model and data analyses; for example, to identify whether vortical features propagate at a uniform alongshore velocity (independent of distance offshore), or whether they are tied to the local Lagrangian flow (as indicated, for example, by bubble cloud advection).

*Wave-current interactions in finite depth*

As a first step, we build on some previous work regarding the vertically integrated momentum equations for both waves and the underlying Eulerian mean flow.

## WORK COMPLETED

*Data analysis and comparison*

The complete data set has been submitted to the public archive at the FRF (K. Hathaway, contact). The data selected for this project is much smaller, and fits on a single DVD along with a set of MATLAB(tm) routines that produce sequences of 2D maps of velocity, vorticity, backscatter intensity (a measure of bubble density), and error estimates. Although the routines are constantly under development, working copies are available on demand (on an "as is" basis).

A major concern in the data is noise. A significant source of noise arises from the presence of many working instrument frames, which are very effective acoustic scattering "targets" (see figure 1).

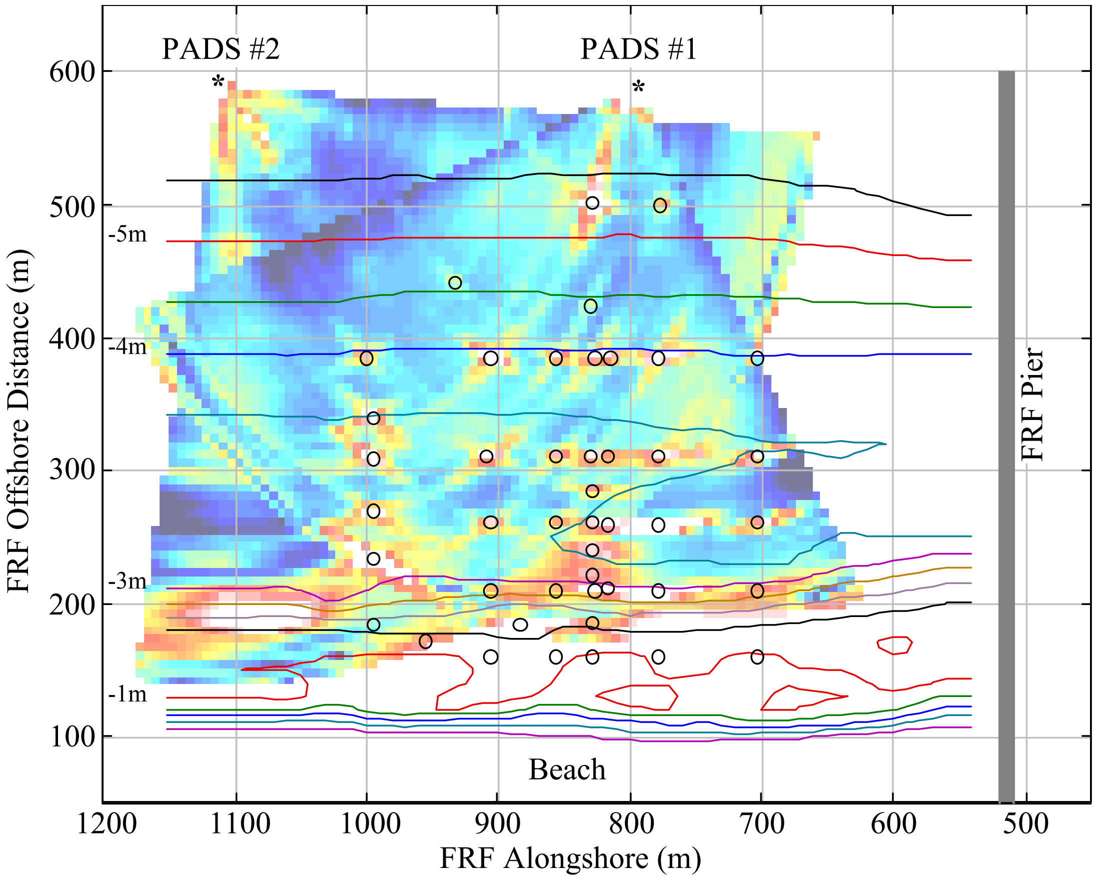


***Figure 1. SandyDuck experimental site, showing areas covered by the phased-array Doppler sonars (PADS). The circles show locations of frames for other instruments nearby. The colors contour the mean backscatter intensity on a particular (calm) day: Blue to black denote lower backscatter regions. Red to white denote the loudest. High backscatter is found near array locations as well as near shore. Note also that the array-induced backscatter is broad in angle and thin in range. North is about 20° clockwise of left. The location is the Field Research Facility of the US Army Corps of Engineers, in Duck, North Carolina..***

We have determined through simulations and data-specific tests that a majority of the resulting errors or noise in the velocity fields are projected into the divergent part of the flow field. The noise introduced to the vortical part is only half as large as the divergent, and hence only 1/3 of the total noise introduced. A very simple and efficient routine, based on FFTs, was developed to separate the continuous, regularly sample fields produced by the dual-PADS analysis into non-divergent and irrotational parts. As an aside, a flow field that is both non-divergent and irrotational can appear in either or partly in both, but the sum of the two fields always reconstructs the original (this technique will no doubt appear soon in an appendix of a paper on this project). This difference this separation makes is noticeable, primarily because of the favorable distribution of noise into the divergent field (which we disregard here). Figure 2 shows a comparison of the total and non-divergent velocity (vectors) superimposed on the estimated vorticity (color contours) for the same time.

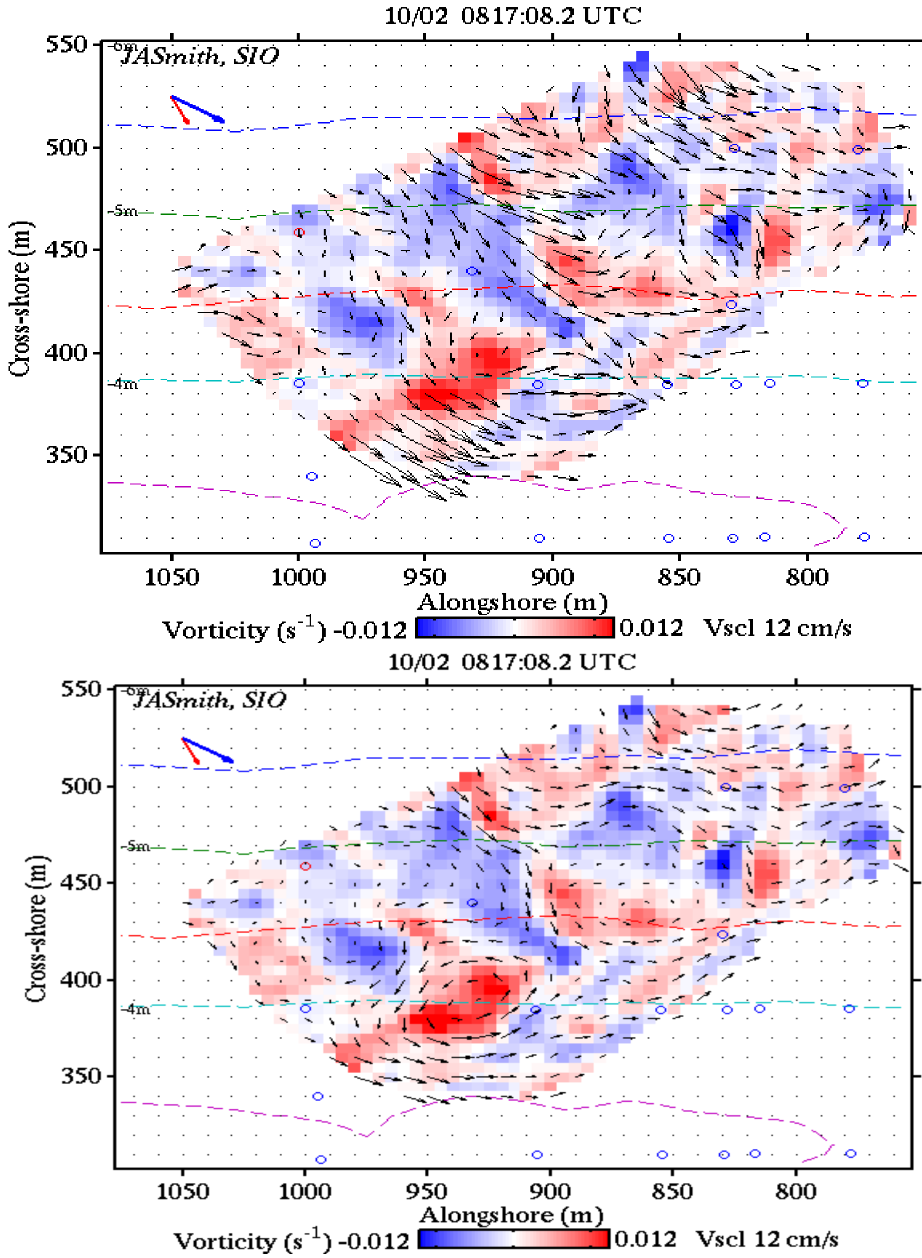


***Figure 2. Example vorticity field with (upper panel) total velocity vectors and (lower panel) velocity vectors for the non-divergent part only (vorticity contours are identical). The area mean velocity variance in the lower panel is about 1/3 that of the upper. Fields are 30 second averages.***

*Wave-current interactions in finite depth*

Vertically integrated equations for wave and mean flow momentum have been re-examined and written up in a paper submitted to JPO (reviews received, publish with revisions recommended; most recent preprint/reprint is available at http://jerry.ucsd.edu/JSmith_PDF/jsmith_pubs.html ). This was also partly motivated by an unrelated project regarding the scaling of Langmuir circulation (ONR

N00014-02-1-0855), in which it was discovered that the predicted response to passing wave groups is not consistent with the observations (preprint available at same address; this paper has been resubmitted with the recommended revisions).

## RESULTS

Preliminary examination of the data indicates that the vorticity features advect with the same speed as bubble clouds (which are thought to act here as "passive tracers"). However, there is not significant shear offshore of the surfzone, so it is hard to say yet with certainty that they are not associated with shear wave activity in the nearshore alongshore jet.

On occasion, vortices are seen that are relatively long-lived (e.g., over 20 minutes in one case). Such long-lived closed vortices can be effective at transporting materials. On the other hand, the vorticity is most often seen to evolve fairly rapidly, which would appear to imply enhanced mixing.

## IMPACT/APPLICATIONS

Transport and mixing of materials near shore has broad implications, from dispersal of pollutants to fish recruitment, from bottom morphology to sediment transport. The action of vortical motions is central to this. Understanding how wave forcing affects the motions, including this "turbulence," is central to understanding the system.

Wave-current interactions are a significant influence near shore, and (indeed) in the oceans in general. Improved understanding, and validation of the results, has the broadest possible implications

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